# New phenomena searches at Tevatron Run I

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# New Phenomena Searches at TEVATRON Run I

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**On behalf of CDF and D0 collaborations**

## Outline

- Run I at the TEVATRON
- Search for SUGRA:
  - dilepton channel at CDF
  - electron channel at D0
- Search for large ED:
  - monojet channel at D0
  - diphoton channel at CDF
- Conclusions

# Collider in Run I


Proton-Antiproton Collisions

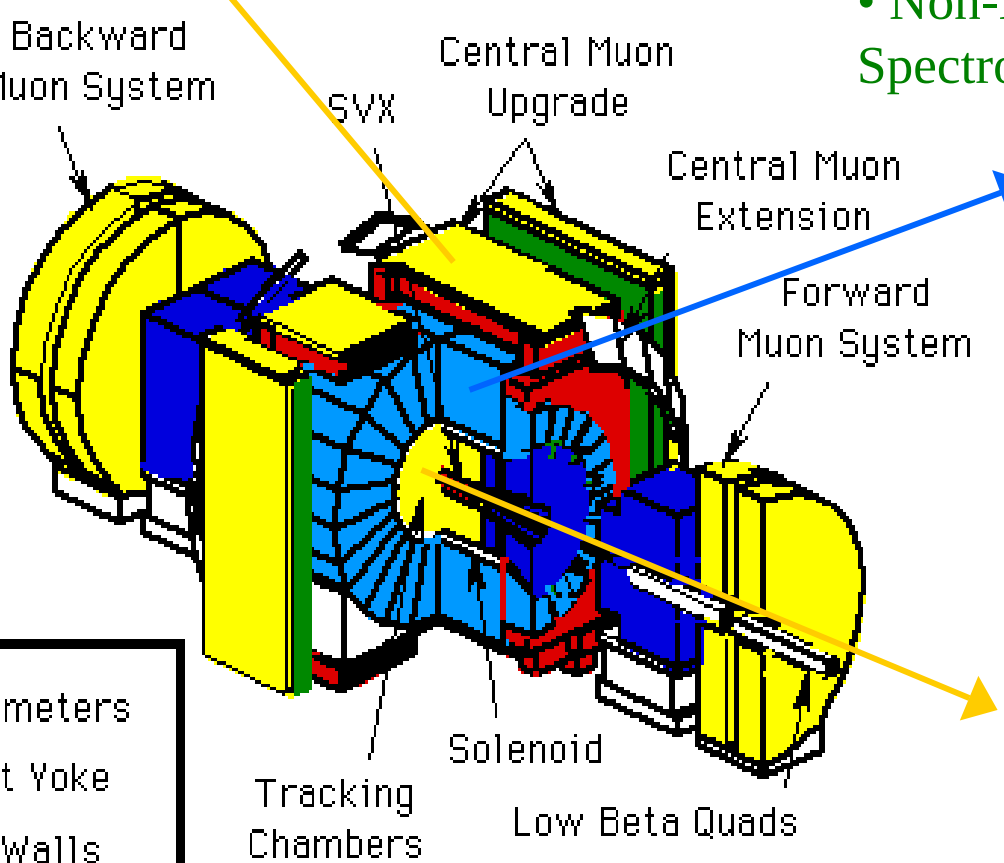
| $\sqrt{s}$ | $L$ | $\Delta t_X$ | Period |
|---|---|---|---|
| $1.8\,TeV$ | $2\times10^{31}\,cm^{-2}s^{-1}$ | $3.5\,\mu s$ | 1992-1996 |

# Detectors in Run I

*Muon*:

$\sigma(r\varphi) = 250\,\mu m\,(CMU)$

## CDF Detector




- Silicon Vertex Detector
- Large Magnetic TrackingVolume
- Non-Magnetic Central Muon Spectrometer (Forward Toroid)

*Calorimeter :*

$$\frac{\sigma_{EM}}{E} = \sqrt{\left(\frac{13.5\%}{\sqrt{E_T}}\right)^2 + (2\%)^2}$$

$$\frac{\sigma_{HAD}}{E} = \sqrt{\left(\frac{75\%}{\sqrt{E_T}}\right)^2 + (3\%)^2}$$

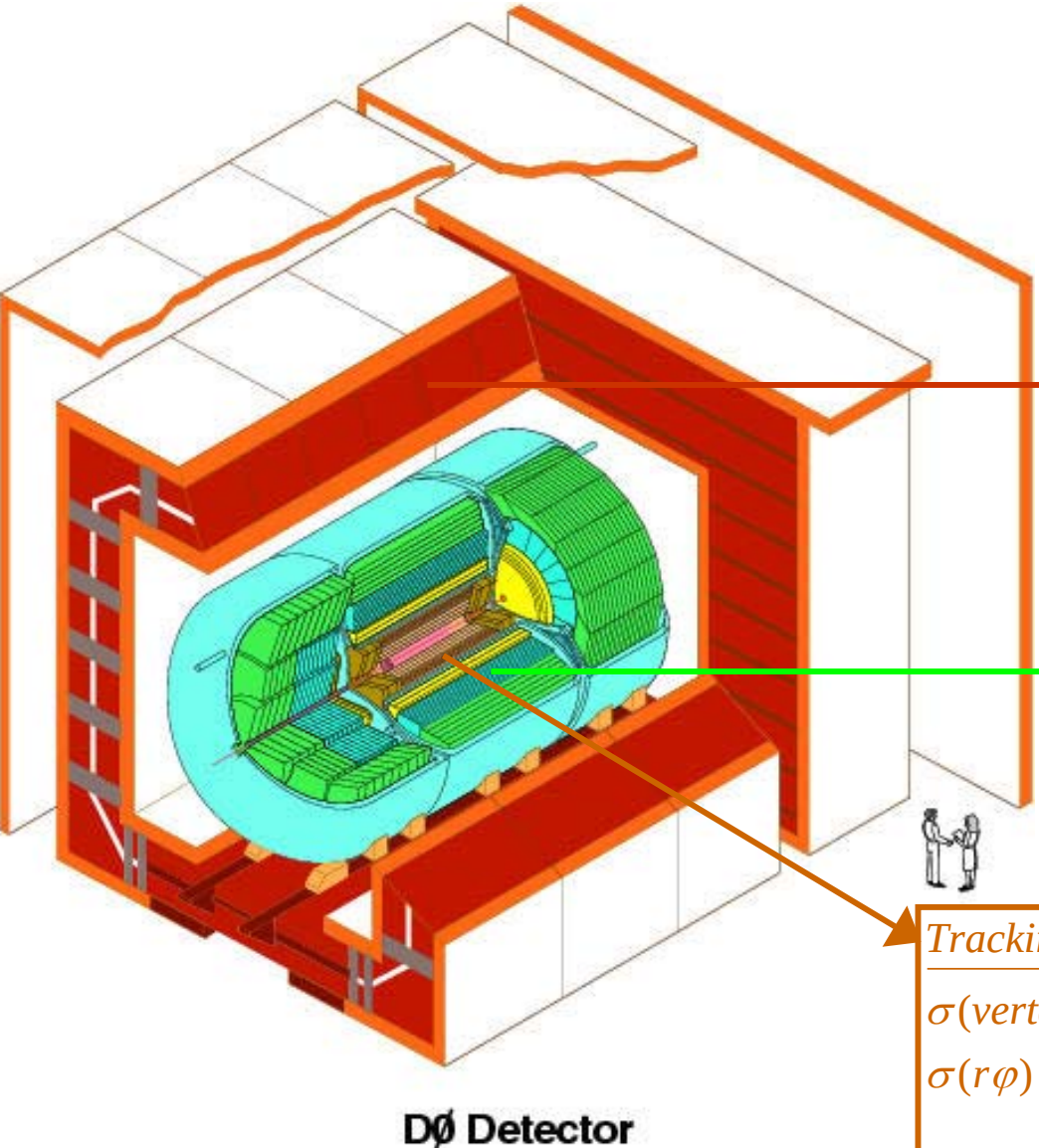
*Tracking :*

$\sigma(r\varphi) = 17\,\mu m\,(SVX)$

$\sigma(z) = 1\,mm\,(VTX)$

$$\frac{\Delta p_T}{p_T} \approx (0.1\%) \times p_T\ (SVX + CTC)$$

# Detectors in Run I




- Good Calorimetry: hermeticity, resolution
- Iron Toroid Muon Spectrometer, Large Acceptance

*Muon :*

$|\eta| < 3.3$

$\frac{\Delta p}{p} = 0.2 \oplus 0.003\, p$

*Calorimeter :*

$\frac{\sigma_{EM}}{E} = \frac{15\%}{\sqrt{E}} + 0.3\%$

$\frac{\sigma_{HAD}}{E} = \frac{45\%}{\sqrt{E}} + 4\%$

*Tracking :*

$\sigma(vertex) = 6\ mm$

$\sigma(r\varphi) = 60\ \mu m\ (VTX)$

$= 180\ \mu m\ (CDC)$

$\sigma(r\varphi) = 200\ \mu m\ (FDC)$

# SUGRA Models

RPC Gravity Mediated SUSY Breaking (MSSM, mSUGRA)

**MSSM Particle Content:**

| S=1 | S=1/2 | S=0 |
|---|---|---|
| | $l$ | $\tilde{l}$ |
| | $q$ | $\tilde{q}$ |
| $g$ | $\tilde{g}$ | |
| $W^{\pm}$ | $\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_2^{\pm}$ | $\phi_1^{+}$ $\phi_2^{-}$ |
| $\gamma$ <br> $Z$ | $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$ <br> $\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ | $\phi_1^0$ $\phi_2^0$ |

$$M_{\tilde{t}}^2 = \begin{pmatrix} m_{\tilde{t}_L}^2 + m_t^2 & m_t(A_t - \mu/\tan\beta) \\ m_t(A_t - \mu/\tan\beta) & m_{\tilde{t}_R}^2 + m_t^2 \end{pmatrix}$$

**MSSM Phenomenology:**

Parameters:

- $m_{1/2}$ : universal gaugino mass
- $A_0$ : universal trilinear coupling
- $\mu$ : higgsino mass parameter
- $\tan\beta$ : ratio of 2 Higgs doublets vev
- $m_0$ : universal scalar mass

R Parity: $R_P = (-1)^{L+2S+3B}$

Conservation:

- Sparticles pair production
- LSP $\tilde{\chi}_1^0$ stable $\Rightarrow$ $E_T^{miss}$ signature

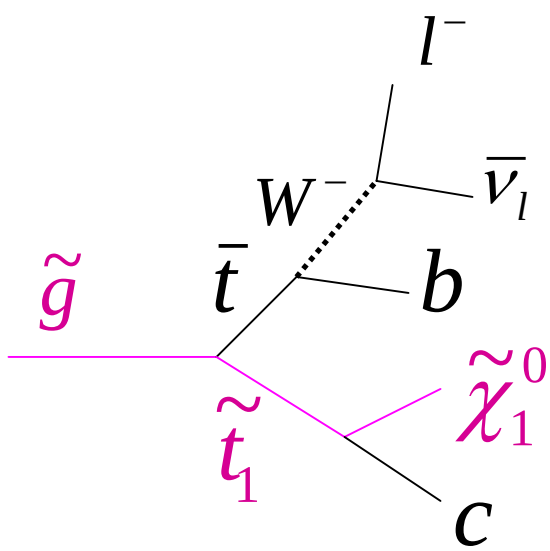
# SUGRA in dileptons at CDF

## Gluino Pair Production

LO contributions:

$$gg \to \tilde{g}\tilde{g}$$

$$q\bar{q} \to \tilde{g}\tilde{g}$$




## Gluino and Stop Decays

$$\tilde{g} \to t\bar{\tilde{t}}_1 / \bar{t}\,\tilde{t}_1$$

$$\tilde{g} \to t\bar{\tilde{t}}_1 / \bar{t}\,\tilde{t}_1$$

- gluino: Majorana sparticle

$$\tilde{t}_1 \to c\,\tilde{\chi}_1^0 \quad \text{(stop NLSP)}$$

$$t \to W^{\pm} b \to l^{\pm} \nu b$$

## Main SM Backgrounds

## Final State Topology

Top dilepton events

Like-sign: $l^{\pm}l^{\pm} + jets + E_T^{miss}$

(Opp-sign: $l^{\mp}l^{\pm} + jets + E_T^{miss}$ )

- Very low
- Fake lepton $(W^{\pm} + \geq 3\ jets)$
- SM Top pair production
- Diboson production

# SUGRA in dileptons at CDF

Analysis

$$\int L\,dt = 106.1\ pb^{-1}$$

- Trigger: L3 inclusive electron or muon (isolation, pT>13-15 GeV,…)
- Lepton ID: track matching (e), shower shape (e), track-calo. isol. (both),
- Remove: conversions (e), cosmics (mu), Z peak (both), radiative Z
- Etmiss: $E_T^{miss}$ >25 GeV (isolated)
- Jets: at least 2 central jets with $p_T > 10\,GeV$

Selection Results

Expected events: $0.67^{+0.55}_{-0.24}$

- $0.37 \pm 0.23$ ( *fake leptons* )
- $0.28 \pm 0.07$ ( $t\bar{t}$ ),...

Observed events: 3

- 2 $e\ \mu$
- 1 $e\ \mu\mu$

# SUGRA in dileptons at CDF

## Interpretation of Run I Result

Preliminary 95% *CL Limits*

- Limit on cross section:

$$\sigma_{\tilde{g}\tilde{g}} < 15.1 - 18.0\ pb$$
$$(200 \le m_{\tilde{g}} \le 320\ GeV)$$

$$(BR(\tilde{g} \to t\,\tilde{t}) = 1)$$

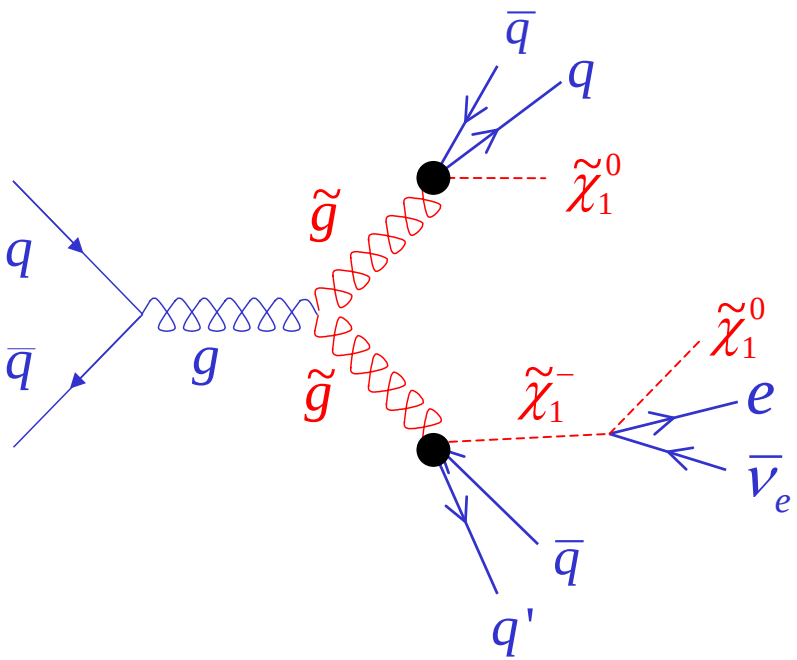
- Mass limit:

$$m_{\tilde{g}} > 180\ GeV$$

# mSUGRA in electrons at D0

## Gluino Pair Production/Decay

$$gg \rightarrow \tilde{g}\tilde{g}$$
$$q\bar{q} \rightarrow \tilde{g}\tilde{g}$$




## Final State Topology

$$e^{\pm} + (\geq 4\ jets) + E_T^{miss}$$

## Motivation

- Signal sensitive to high and moderate $m_0$ region: complement to (dilepton and jets)+$E_T^{miss}$

## Main SM Backgrounds

$$W^{\pm} + jets, t\bar{t}, QCD$$

# mSUGRA in electrons at D0

Selection: NN (9-18-1)

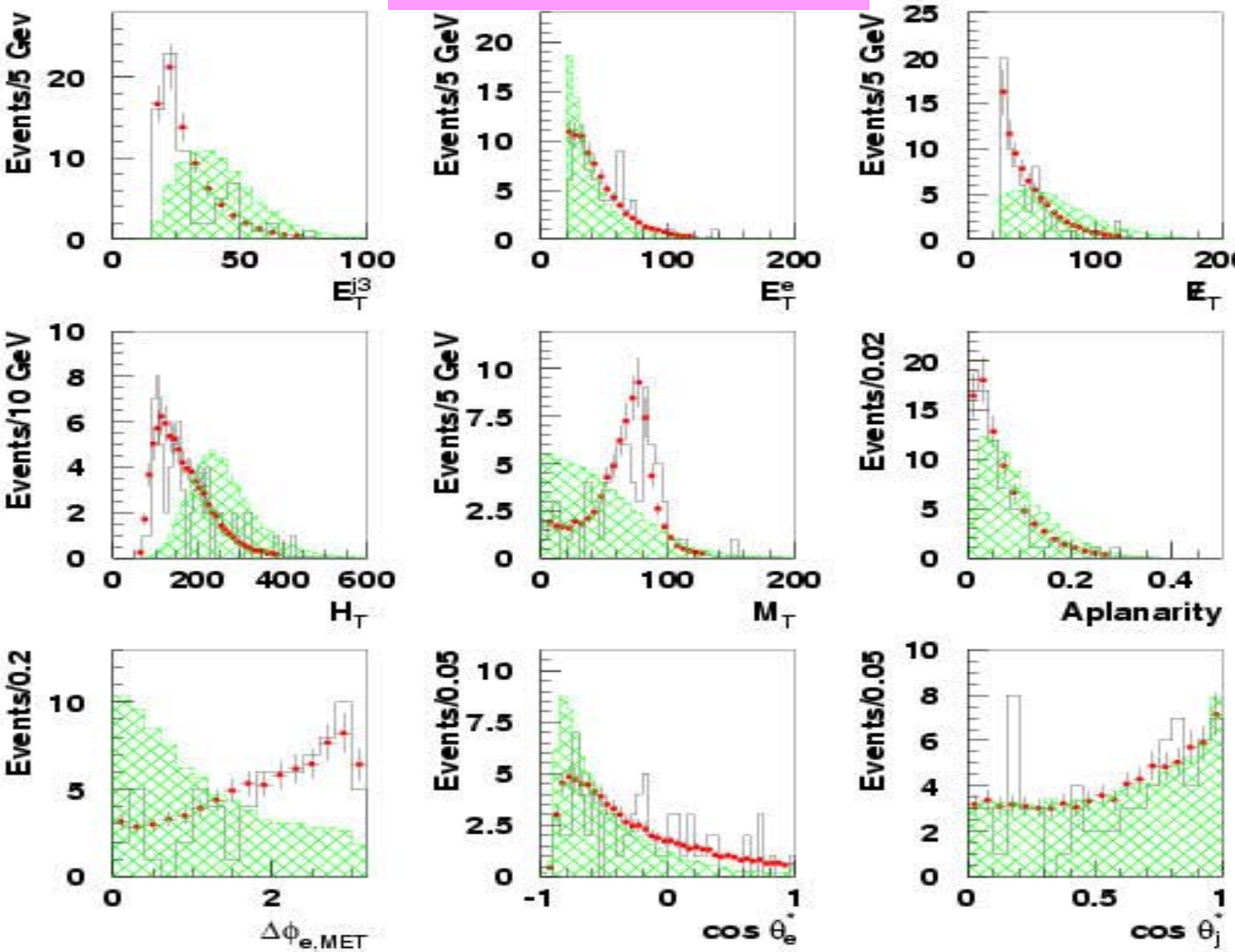
$\int L\,dt = 94\ pb^{-1}$

Preselection

$E_T(e^{\pm}) > 20\,GeV$

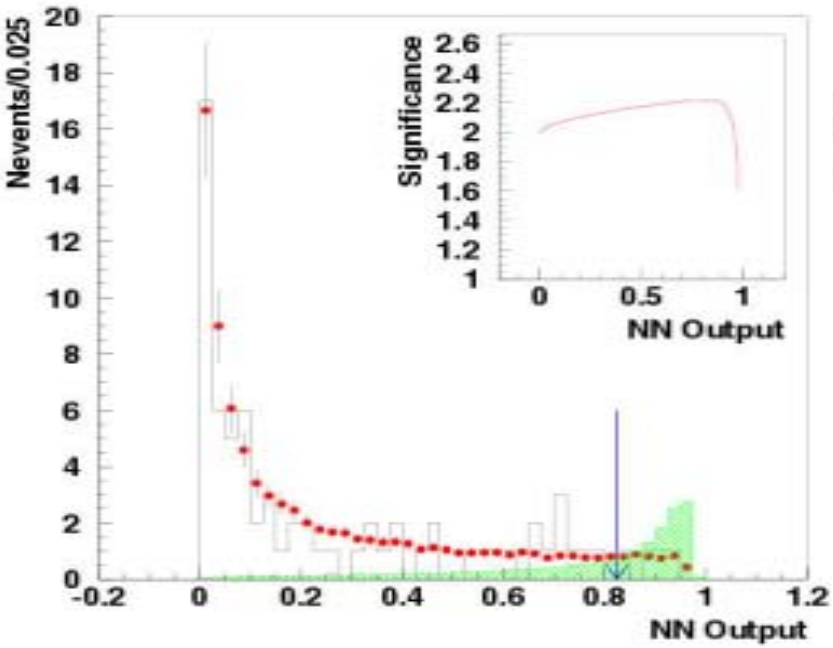
$E_T(jets) > 15\,GeV$

$E_T^{miss} > 25\,GeV$



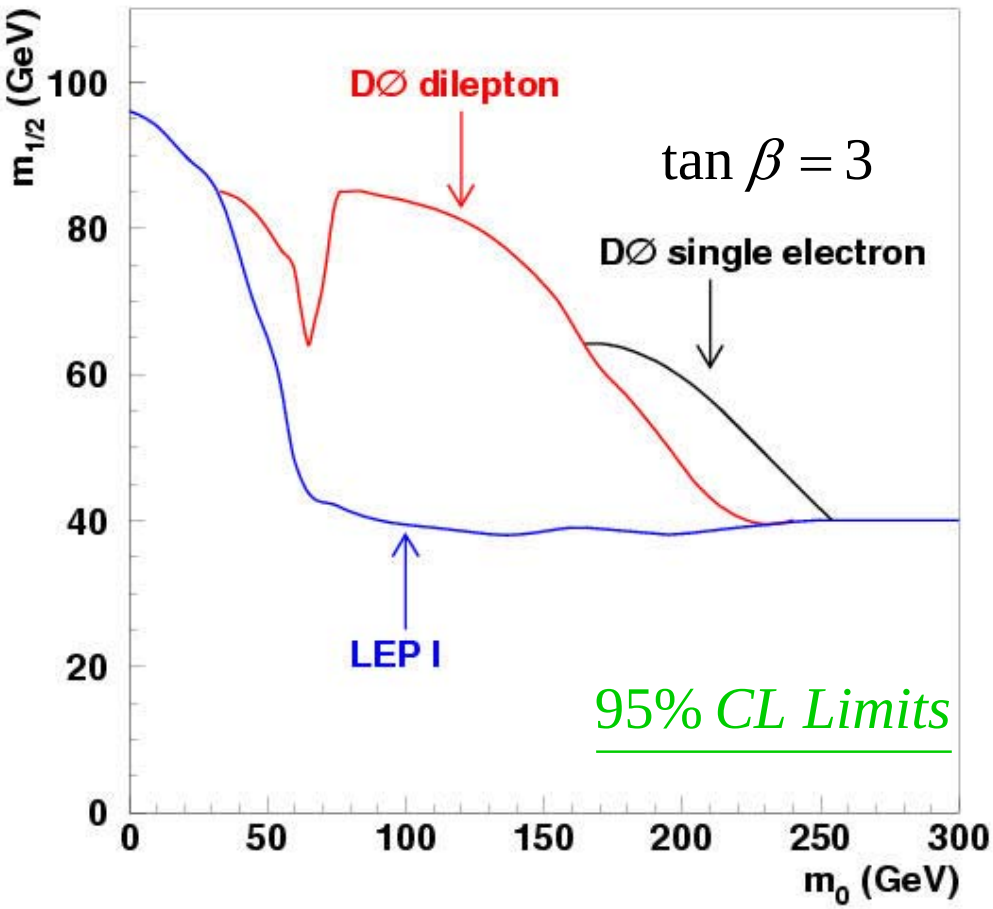
# mSUGRA in electrons at D0

## Results




- t tbar : 16.8 ± 5.2
- WW + ≥ 2 jets : 1.4 ± 0.3
- QCD Multijet: 19.1 ± 4.7
- W + ≥ 4 jets : 43.0 ± 7.6
- **Expected Events: 80.3 ± 10.4**
- **Observed Events: 72**

## mSUGRA Limit



# Large Extra Dimensions

Theoretical Foundation:

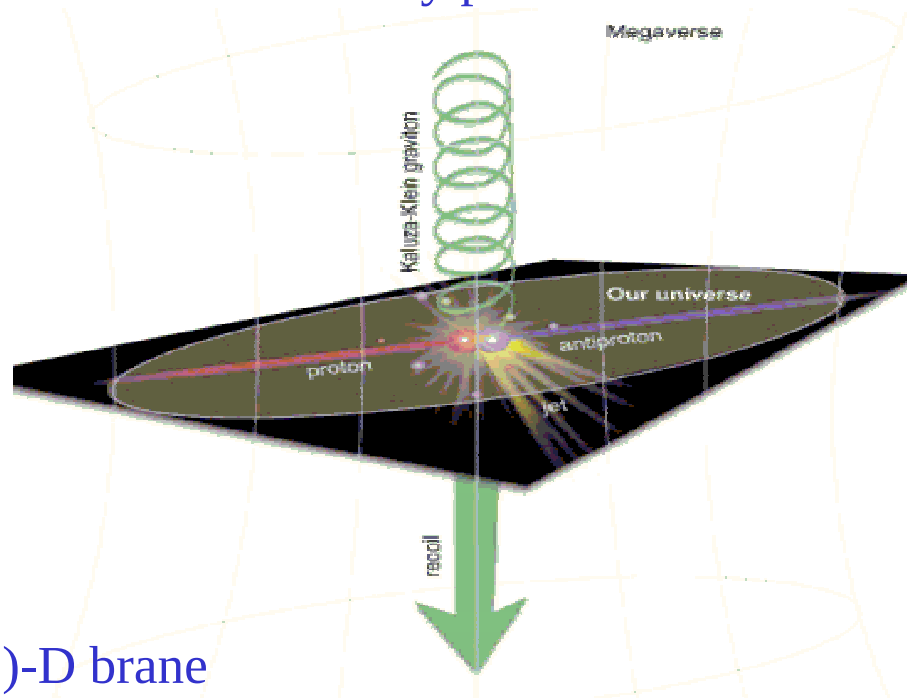
- Quantum gravity scale $M_D$ can be O(1 TeV), solution to hierarchy problem

¨Modified¨ Gravity:

$$\underline{4-D} \qquad \underline{(4+n)-D}$$

$$G_N^{-1} \sim M_{Pl}^2 \longrightarrow G_N^{-1} \sim R^n M_D^{2+n}$$

R: compactification (torus) radius




Phenomenology:

- SM particles (open strings): confined to (3+1)-D brane
- Graviton (closed strings): can propagate in the bulk (¨weakness of gravity¨)
- Equivalence: massive gravitons (KK) in 4-D and massless gravitons (4+n)-D
- Ref: Guidice, Rattazzi, Wells, NPB 544 (1999)
- Ref: Arkani-Hamed, Dimopoulos, Dvali, PLB 429 (1998)
- Ref: Antoniadis, PLB 246 (1990)

# Large ED Searches at Colliders

## ED Nbers and Radii

$$M_D \approx 1 TeV$$

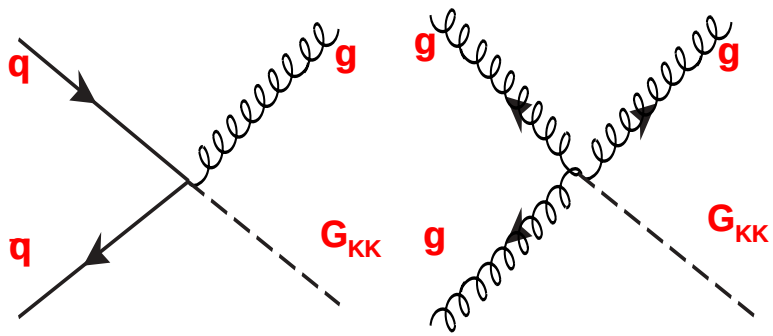
$$R = \begin{cases} 1.2\times10^{12}\, m & n=1 \\ 0.48\, mm & n=2 \\ 3.6\, nm & n=3 \\ 9.7\times10^{-12}\, m & n=4 \end{cases}$$

Eöt-Wash Experiment
Test Newton's Law downto
$O(200\ \mu m)$
Ref: Adelberger et al, PRL 86 (2001)

## Production Mechanisms

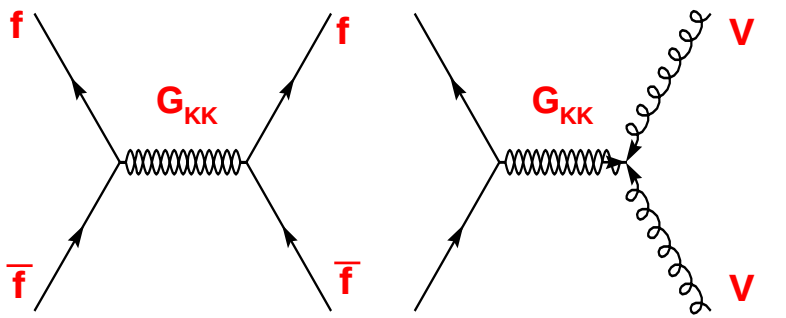
### Real Gravitons

Monojets at hadron colliders




### Virtual Gravitons

Fermion or VB pairs at hadron or $e^+e^-$ colliders

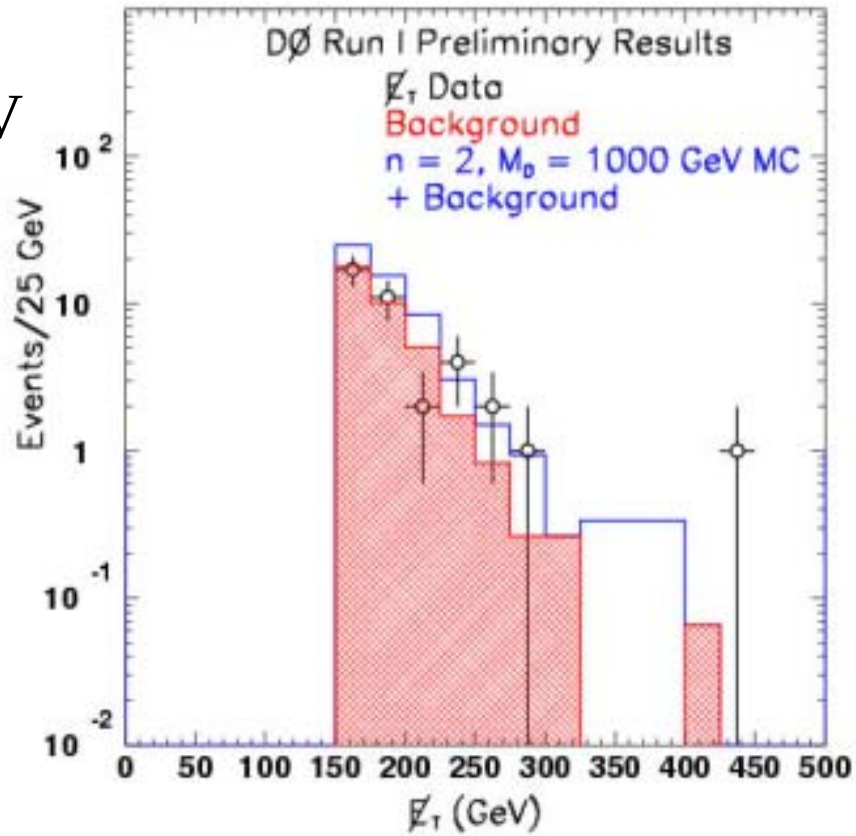


# LED in monojets at D0

$\int L\,dt = 78.8\ pb^{-1}$

## Selection

- $N_{jets}$ = 1 or 2
- $E_T(j_1)$ >150 GeV, $E_T(j_2)$ < 50 GeV
- $j_1$ central (good quality)
- $E_T^{miss}$> 150 GeV
- Reject events with isol. muons,
- Reject cosmics




## Results

WZ background = 30.2 ± 4.0

QCD background = 7.9 ± 7.1

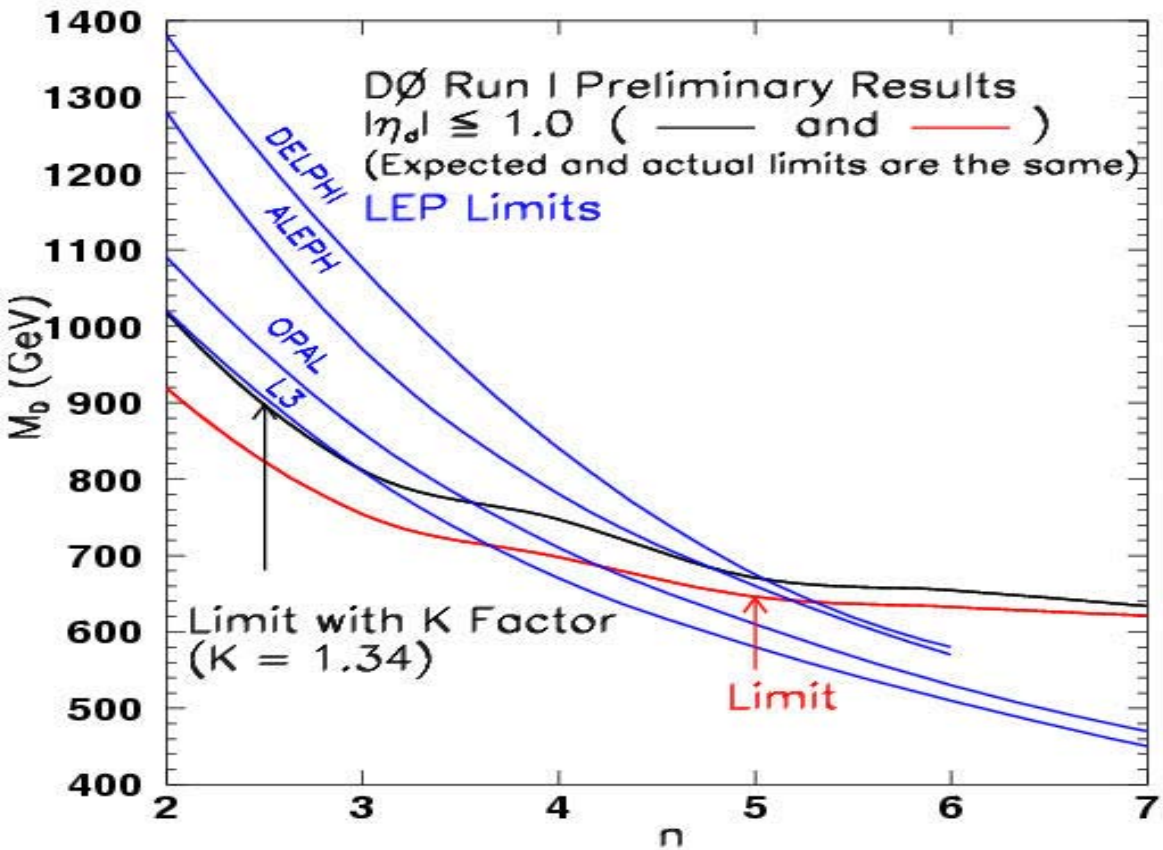
Expected Events = 38.0 ±8.2

Observed Events = 38

# LED in monojets at D0

Limits

95% *CL Limits*




n=4

$M_D$>698 (840) GeV

**D0 DELPHI**

**Conservative Limit (no K-factor)**

n=6

$M_D$>632 (580) GeV

**D0 DELPHI**

# LED in diphotons at CDF

## Signal

$q\bar{q} \rightarrow G_{KK} \rightarrow \gamma\gamma$

## Backgrounds

γ+jets

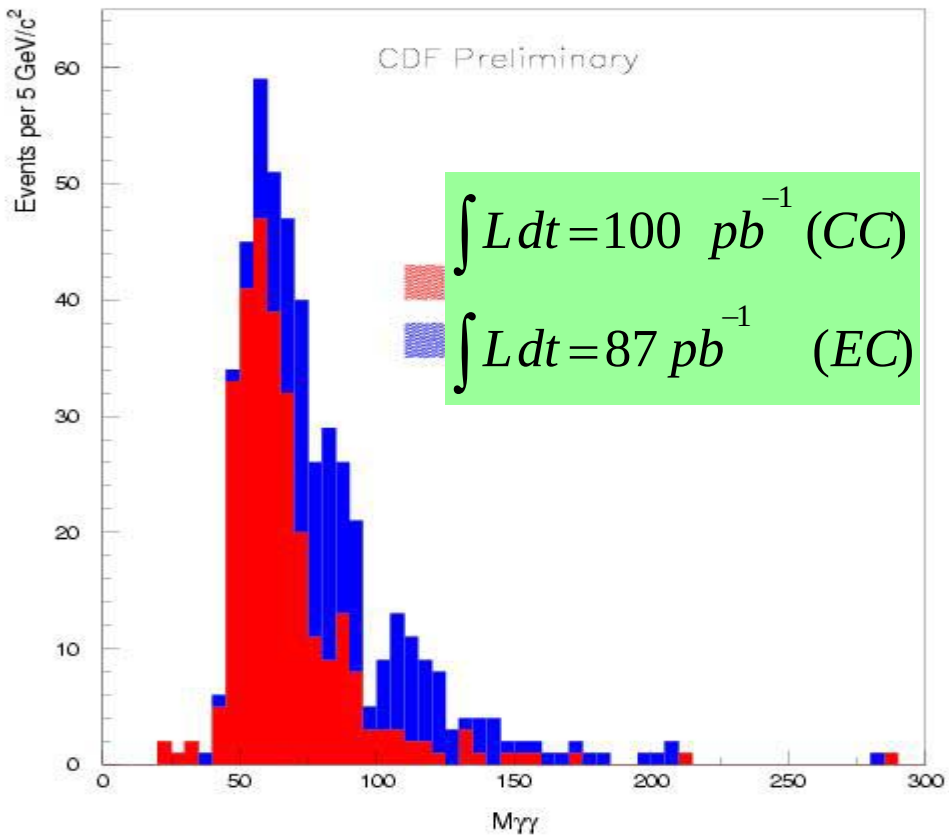
QCD dijets

## Selection

- Isolated photons
- $E_T(\gamma) > 22$ GeV, $|\eta(\gamma_1)| < 1.0$

## Results

| | Central | EndCap |
|---|---|---|
| Observed | 287 | 192 |
| Expected | $280 \pm 70$ | $208 \pm 42$ |
| SM diphotons | $96 \pm 31$ | $76 \pm 31$ |
| Bkgd from fakes | $184 \pm 63$ | $132 \pm 28$ |

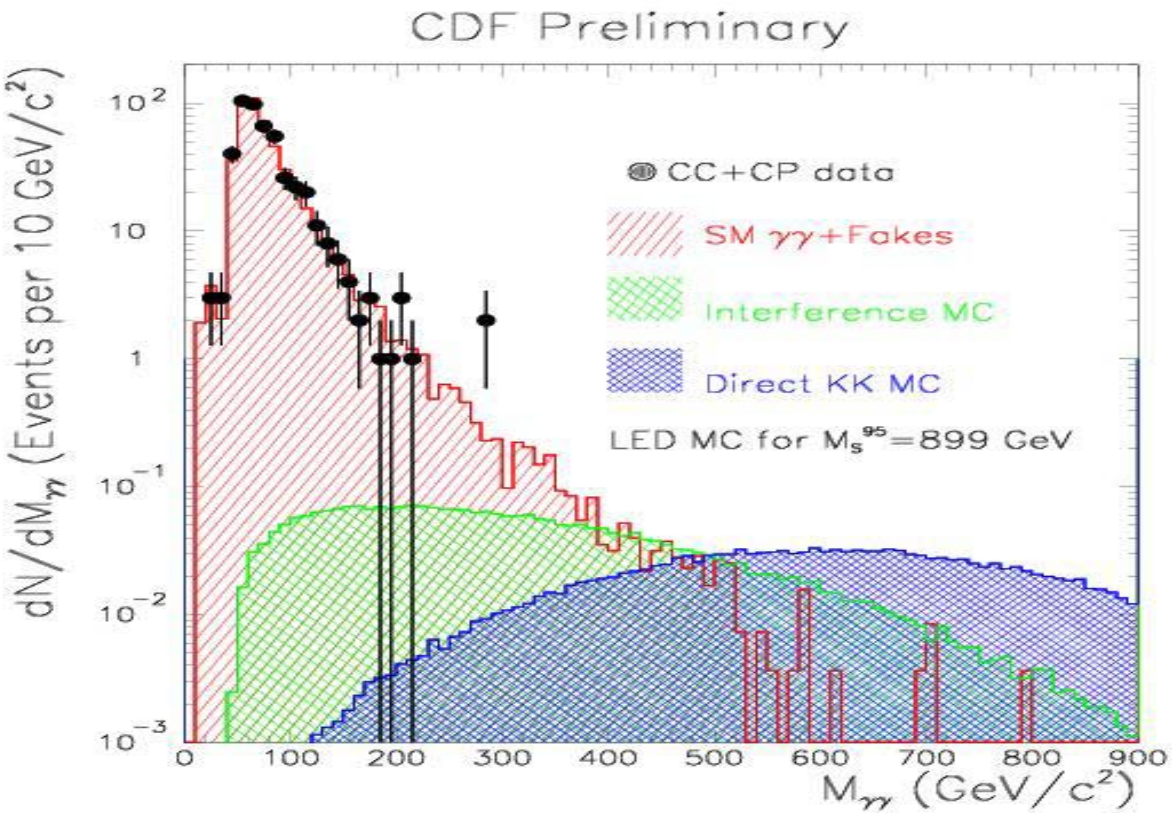


# LED in diphotons at CDF

- Cross section of:

$$p\bar{p} \to q\bar{q} / gg \to \gamma\gamma + X$$

$$\frac{d\sigma}{dM_{\gamma\gamma}} = \left.\frac{d\sigma}{dM_{\gamma\gamma}}\right|_{SM} + \eta \left.\frac{d\sigma}{dM_{\gamma\gamma}}\right|_{INT} + \eta^2 \left.\frac{d\sigma}{dM_{\gamma\gamma}}\right|_{KK}$$




- Free parameter to fit:

$$\eta = \frac{\lambda}{M_D^4}$$

**Limits**

*CDF*

$M_D > 1.01 TeV$

(This analysis)

*D0*

$M_D > 1.21 TeV$

- Add cosθ* to fit, 127pb$^{-1}$
- Ref: PRL 86 (2001)

95% *CL Limits*

# Conclusions

- New Analyses of Run I Data
- Better sensitivity:
  - Improved Selection Techniques
  - Use of Full Calorimeter Acceptance
- Resulting in:
  - Improved Limits
  - Complementary and Competitive wrt LEP II
- Next Moves Have Just Started in Run II:
  - Slightly Higher Energy
  - Higher Luminosity
  - Upgraded Detectors
  - Improved Trigger Designs … News Soon

# Large ED Searches

Different theoretical notations

$$\lambda_{GRW} = \frac{-2}{\pi}\lambda_{Hew.}$$

$$\lambda_{Hew.} = O(\pm 1)$$

Dimensionless parameter
Sign: destructive or constructive interference

# Prospects for Run II

## mSUGRA search in dileptons at CDF

- Estimated limit: $m_{\tilde{g}} > 181-182\,GeV \rightarrow m_{\tilde{g}} > 280-295\,GeV$

(same observed and expected events than Run I analysis, with 2 $fb^{-1}$)

## LED search in monojets at D0

- n=2: sensitive to $M_D$=920 → 1400 GeV
- n=5: sensitive to $M_D$=700 → 900 GeV

(with 2 TeV and 300 $pb^{-1}$)